A Modified Hybrid Algorithm Approach for Solving Harmonic Problems in Power Systems

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***Abstract*—A fundamental problem with electrical systems' power quality is electrical harmonics. In order to limit harmonics and their effects on power systems, filters used in electric power systems must be designed with the consideration of power harmonics. The study's suggested approach differs from other hybrid strategies that have been previously published, and the processes that are expected mostly center on cutting down on computing complexity and time. The voltage and current waveforms of distribution networks have started to be significantly distorted over the past 20 years due to the increased use of power electronic equipment and non-linear loads. This paper provides a new hybrid approach for harmonic estimation. Harmonic estimation of these deformed waveforms is a nonlinear problem because sinusoidal waveforms contain nonlinear distortions. As a result, the corresponding combined technique splits the problem of harmonic estimation into two independent problems due to the slow convergence of nonlinear problems in the estimate of harmonic components. The algorithm used in this study first estimates amplitude and frequency using the fuzzy logic control (FLC) approach, a non-linear estimator. The objective function is then to minimize the error value for both the original signal and the estimated signal using the genetic algorithm, a non-linear estimator. The experiments show that the proposed method for determining harmonic estimation time is 36% better than comparable methods. As a result, the suggested technique offers a number of benefits, including very quick computation times, more precise evaluation of amplitude and phase values for all conditions, and complexity in the outcomes.**

Keywords*—Harmonic estimation; fuzzy PD controlled; harmonic components

I. INTRODUCTION

The periodic harmonic of current and voltage waves in an electrical network is undesirable because it increases the non-linear load and temporal unpredictability of the system [1]. The waveform and voltage contain a sinusoidal component with a different frequency known as harmonics due to this non-linear load or device[2]. The fundamental elements' integer repeating frequencies are known as harmonics. When harmonics are present, the power factor quality deteriorates, which causes issues with system protection, performance, and improvement [3]. In commercial and industrial systems, the increased usage of non-linear loads such as diodes and rectifier thyristors, arc furnaces, printers, uninterruptible power supply (UPS), etc., is one of the main contributors to harmonic generation. For an accurate computation, the primary frequency's range and phase are necessary [4]. The fast Fourier series transform (FFT) is the foundation of the conventional method of harmonic estimation [5]. However, the FFT-based approach has the issue of an undesired spectrum impact despite offering outstanding performance in noise [6]. One of the effective techniques for determining the number of harmonics in this situation is the Kalman filter [7]. However, tracking dynamic changes in the measurement signal with this Kalman filter fails [8]. Because of this, the amplitude and phase of voltage and current signal harmonics are evaluated using the least square algorithm [9].

Washing machines, video cameras, gas stoves, as well as industrial activities like cement kilns, underground trains and robots, are all controlled by fuzzy controllers [10]. A control strategy based on fuzzy logic is known as fuzzy control [11]. It should be emphasized that fuzzy logic and fuzzy control can both be summarily defined as calculations with words rather than numbers and phrases, respectively [12]. In operator-controlled systems, a fuzzy controller with empirical rules is very helpful [13]. The control strategy is saved in one or more natural languages in a rule-based controller [14]. Disturbances and disturbances that can be measured are corrected [15]. This approach needs a strong model. However, a fuzzy model might be helpful if a mathematical model is challenging to develop [16].

Because they don't need a precise mathematical model, fuzzy logic controllers have an advantage over traditional PI controllers [17]. They may be non-linear, able to handle ambiguous inputs, and more durable than a typical PI controller [18]. Fuzzy logic has been used by many writers to develop cutting-edge techniques for reducing harmonics and enhancing power quality [19]. Fuzzy logic in fuzzy logic box software should be understood as FL, or fuzzy logic in its fullest definition [20]. Fuzzy Logic's foundations provide a thorough explanation of FL's core concepts. Fuzzy control, which is based on approximate reasoning simulations and fuzzy mathematical theory, is a crucial subfield in intelligent control [21]. As a result, it can offer a wise way to manage intricate systems. Fuzzy systems typically include two components [22]. A segment is distinct and governed by regulations. One component is continuous and is known as a "fuzzy set". In recent years, the genetic algorithm has been combined with these two sets to be used for harmonic control [23]. Genetic algorithms are based on natural evolutionary processes like selected mutation. Since they were first developed approximately 25 years ago, genetic algorithms have shown to be a highly effective method for addressing a variety of AI-related issues [24]. In order to achieve optimal solutions/allocation and restrict the harmonic contents of DSs, it has been explored which planning models, optimization techniques, and renewable energy sources have used uncertainty models to solve BESS/PVDGs allocation difficulties. Studies on BESS/PVDG allocation planning, however, have managed to reduce costs while falling short of the DSs standard harmonic level [25]. A hybrid fuzzy-genetic method is suggested to get over traditional fuzzy logic's constraints [26]. A fuzzy genetic algorithm (FGA) is a type of genetic algorithm that enhances various types of genetic algorithm behavior using fuzzy logic methods or fuzzy tools. An FGA can be thought of as a set of instructions, some of which may be constructed using fuzzy logic tools like fuzzy operators and connections to create genetic operators with various features [27]. They also examine the harmonic characteristics of various sources in typical operating scenarios, such as typical residential electrical load, electric vehicle charging scenario, frequency converter speed regulator, and renewable energy generation. Researchers have provided a comprehensive overview of common models of harmonic sources in modern power systems and provided insight into the circuit mechanisms, mathematical models, and operational processes of these sources [28].

The present study proposes a modified hybrid algorithm approach to solve harmonic problems in power systems. The main focus of the study is on electrical power quality and the issue of electrical harmonics in power systems. The suggested approach in this study differs from previously published hybrid strategies, with a focus on reducing computing complexity and time. The algorithm used in this study first estimates amplitude and frequency using the fuzzy logic control (FLC) approach, which is a non-linear estimator. Then, the objective function is to minimize the error value for both the original signal and the estimated signal using the genetic algorithm, another non-linear estimator. The combination of the two fuzzy logic algorithms and the genetic algorithm improves the simultaneous estimation of harmonic amplitude and phase components of the system. The study evaluates the proposed approach using two experiments. The first experiment focuses on analyzing power harmonics without combining and coordinating various harmonics, while the second experiment involves estimating real signals close to each other. The results of the experiments indicate that the proposed method outperforms other existing algorithms in terms of estimation performance and computation time. In summary, the main difference between the present study and previous works lies in the novel combination of fuzzy logic control and genetic algorithms to estimate harmonic components in power systems. The proposed method shows better convergence and estimation speed compared to other methods and can accurately estimate harmonic coefficients and phases.

However, based on the presented content, some potential challenges and limitations such as the accuracy of accurate estimation of harmonics in complex and noisy scenarios and the existence of noise and disturbances in real-world power systems may affect the accuracy and robustness of harmonic estimation are present in this study.

Given the benefits that the combined fuzzy genetic algorithm has suggested, FGA is utilised in this study to identify harmonics in the power system. In this instance, the harmonic fuzzy logic will be used first to explain the power system. The target function will then be created using the minimum genetic algorithm based on the signal from the fuzzy harmonic logic.

The following is a summary of the authors' contributions to this study.

- Combining two fuzzy logic algorithms and a genetic algorithm improved the simultaneous estimation of the system's harmonic amplitude and phase components.
- Predictive variables of harmonic coefficients Ai and THETAi phases for the estimated signal were determined based on the squared error cost function of the original and estimated signals. • The Taki-Sugno-type fuzzy preset model and PD control form the basis of the proposed structure.

The remainder of the essay is structured as follows. The system model for harmonic estimation is looked at in Section II. Additionally, the combined FGA method that has been proposed for the study model is provided in this section. The simulation results for the suggested model are discussed in the Section III. The Section IV contains the conclusion and recommendations for future work.

II. The Issue of Harmonic Estimation in Electrical Power Systems

According to the literature, current or voltage harmonics can damage devices, overheat power systems, or trip circuit breakers. Therefore, utilising traditional or optimisation methods, researchers and designers have attempted to solve the aforementioned issues [29]. Due to the amplitude and fuzzy components, it has recently been discovered that harmonic estimation problems have a non-linear structure. Optimization-based techniques demonstrate an efficient and quick solution. Due to this achievement, the amplitude and phase values of high-level harmonic components in various waveforms are estimated and optimised in this study using FGA.

A. Harmonics in the Power System Mathematical Model

The following is an estimation of the power harmonic current or voltage's overall waveform:

$$y(t) = \sum_{m=1}^{M} A_m \sin(\omega_m t + \theta_m) + A_{dc} \exp(-\alpha_{dc} t) + \mu(t) \quad (1)$$

$\omega_m = m2\pi f_0$, the angular frequency of component *m*, f0, the main frequency, $\mu(t)$ additional white Gaussian noise *AWGN* ‘(A_{dc} *exp* $(-\alpha_{dc} t)$, the anticipated damping amount, are all represented by the letters *M*. Harmonic phase values are *mth*, while A_m *and* θ_m are unknown values [30]. The discrete-time signal can be represented as follows when the signal *y(t)* is sampled with a sampling period of *Ts*:

$$y(n) = \sum_{m=1}^{M} A_m \sin(\omega_m nTs + \theta_m) + A_{dc} \exp(-\alpha_{dc} nTs) + \mu(n) \quad (2)$$

Then, in equation (2), the so-called damping Taylor series is used, and the straightforward equation is as follows:

$$y(n) = \sum_{m=1}^{M} A_m \sin(\omega_m nTs + \theta_m) + A_{dc} - A_{dc}\alpha_{dc} nTs + \mu(n) \quad (3)$$

Finally, a universal and straightforward formula for estimating the phase and amplitude of all harmonics is discovered. The linearity of the proposed sinusoidal model is also improved, which allows for the use of effective and reliable optimisation techniques to solve the issue. The sine and cosine functions can be used to rewrite the general waveform shown in equation (3) as follows:

$$y(n) = \sum_{m=1}^{M}[A_m \sin(\omega_m nTs)cos\theta_m + A_m cos(\omega_m nTs)sin\theta_m + A_{dc} - A_{dc}\alpha_{dc}nTs + \mu(n)] \quad (4)$$

Later, this signal is transformed as follows into a parametric form:

$$y(n) = H(n)\theta(n) \quad (5)$$

Which H (n) is displayed as follows:

$$H(n) = [\sin(\omega_1 nTs)\ cos(\omega_1 nTs) \ldots \sin(\omega_m nTs)\ cos(\omega_m nTs) 1 - kTs]^{T} \quad (6)$$

Following is how the general vector of unknown parameters is expressed:

$$\theta(n) = [\theta_{1n}\theta_{2n} \ldots \theta_{(2m-1)n}\ \theta_{2mn}\theta_{(2m-1)n}\theta_{(2m-1)n}]^{T} \quad (7)$$

$$\theta = [A_1 cos(\theta_1)A_1 sin(\theta_1) \ldots A_m cos(\theta_1)A_{1m} sin(\theta_1) \ldots A_{dc}A_{dc}\alpha_{dc}]^T \quad (8)$$

The harmonic estimation problem's objective function J, which is used to optimise the unknown parameters, can therefore be represented as follows:

$$J = \min(\sum_{n=1}^{N} e_n^2(n)) = min(\sum_{n=1}^{N}(yn - y_{nest})) = MSE(yn - y_{nest}) \quad (9)$$

where the estimated output harmonic signal $\hat{\boldsymbol{y}}_{nest}$ is specified, and $\boldsymbol{y_n}$ is the actual harmonic signal detected in the grid or electrical system.

B. Design of a Harmonic Estimator using the Combined FGA Algorithm

This section goes into great length about the harmonic estimation problem in the power system and the integrated approach of the FGA algorithm. The harmonic estimator based on the FGA method is used to solve the synchronisation problem in the following steps:

a) Fuzzy Controller: The effectiveness of fuzzy logic controllers in enhancing transient and steady-state performance is well established. The fuzzy logic controller's function is particularly beneficial because a precise mathematical model is unnecessary [31]. Fig. 1 depicts the fuzzy logic control system's diagram.

This figure's four main functional sections are basic knowledge, fuzzification, inference mechanisms, and de-fuzzification. A database and a legal base make up the knowledge base. The database contains information for appropriate fuzzification operations, inference, and de-fuzzification methods, including input and output membership functions. The language rules that link the fuzzy input variables to the desired control actions make up the rule base. A clear input signal is converted into fuzzy signals through "fuzzification," which can be recognised by the degree of membership in fuzzy sets. Instead of using numerical variables, fuzzy logic makes use of linguistic variables. Fuzzy "if-then" principles and fuzzy reasoning are used in this notion. These findings are helpful in various domains, including robotics, autonomous control, data classification, decision analysis, and expert systems. It uses a non-linear mapping from the input space to the output space. The inference mechanism assesses the control rules. Two types of inference mechanisms predominate [32] are: Mamdani fuzzy inference system for starters, and a system for fuzzy inference by Sogno. The fundamental distinction between these two approaches is how they produce the outcomes of fuzzy rules. Sogno employs linear functions of the input variables, whereas Mamdani uses fuzzy sets for the rule. It should be mentioned that the existing research employed the Sogno technique. The inference system carries out tasks like decomposition and aggregation. If the laws are prevalent, they are reduced to a straightforward rule format. Finally, de-fuzzing transforms murky output signals into audible ones [33].

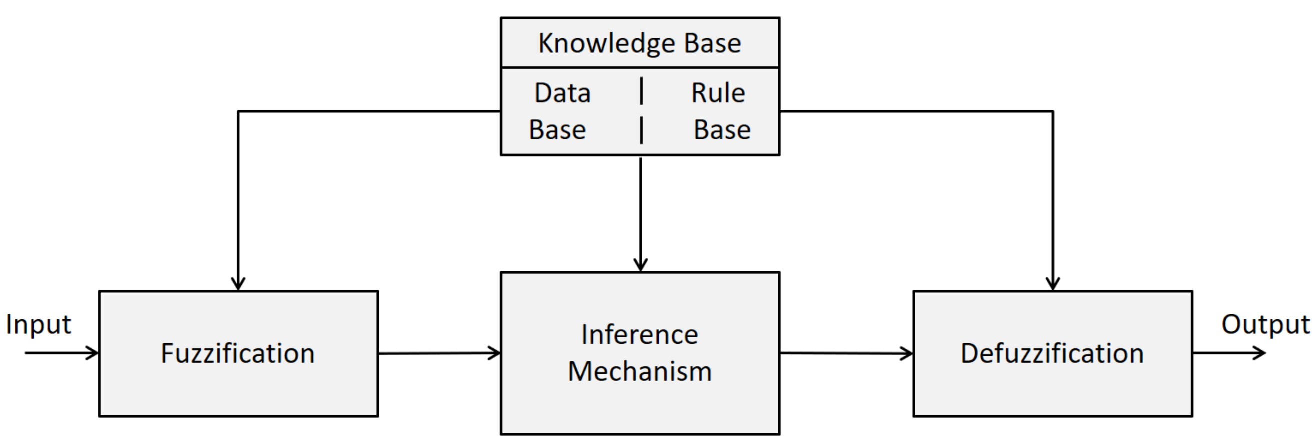

Fig. 1. The fuzzy logic control function block diagram.

b) Genetic Algorithm: General-purpose techniques for learning and optimization are genetic algorithms. A particular kind of evolutionary algorithm called a genetic algorithm uses biological processes like mutation and inheritance. In place of regression-based forecasting methods, GAs is a good choice. Binary strings are the computational language of Gas [34]. Finding a useful answer is only a matter of looking for a particular binary string. Frequently superior to chance-based prediction methods are genetic algorithms. A genetic algorithm, often known as GA, is a programming method that leverages the notion of genetic evolution to solve problems. The input is the problem that needs to be addressed, and the solutions are coded using a structure known as the fitness function [35]. It assesses each potential answer, the majority of which are chosen at random. A helpful technique in pattern recognition, feature selection, picture interpretation, and machine learning are the genetic algorithm. Genetic algorithms replicate the genetic progression of biological things. These algorithms address issues that were motivated by the natural evolutionary process. In other words, they create a population of beings, much like nature does, and by acting on this population, they create an ideal population or being [36].

A problem must be transformed into the unique form needed by genetic algorithms for them to be able to solve it. The required solution to the issue should be developed in this process so that it may be represented as a chromosome [37]. Fig. 2 lists the stages for implementing a genetic algorithm.

a) Proposed Hybrid FGA Algorithm: Fig. 3 displays the harmonic estimation algorithm based on the suggested FGA algorithm. The block diagram view of the suggested design for the problem of signal identification at various times by extending the Fourier series of a signal and calculating the amplitude and phase at various frequencies is really depicted in the accompanying figure. We combined the genetic algorithm with a Taki-Sugno-type fuzzy control to improve the detection accuracy. Additionally, it serves as a PD controller in the control part of the closed-loop system to estimate instantaneous and high-speed harmonics. As a result, it greatly enhances the ability of the genetic algorithm.

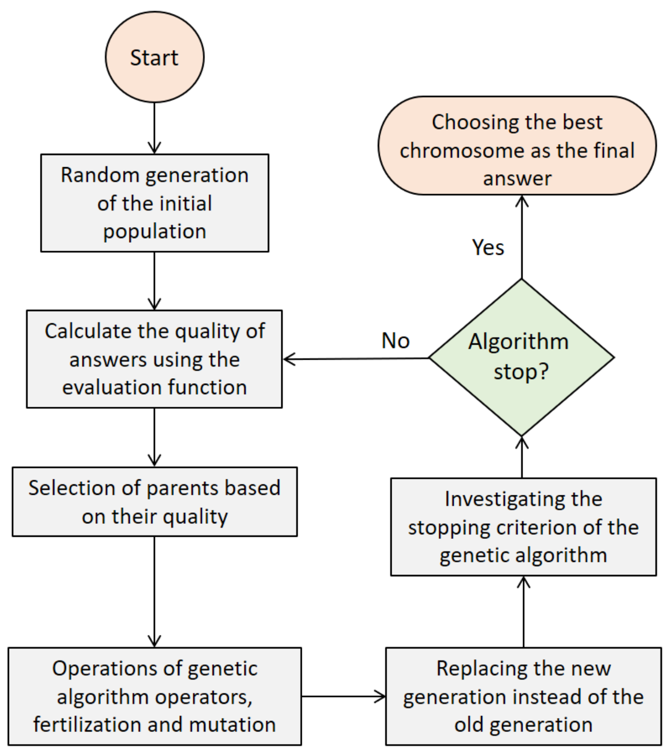

Fig. 2. Shows how the genetic algorithm is applied.

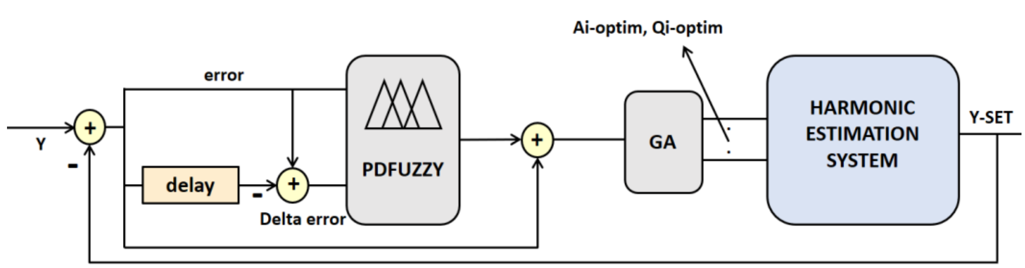

Fig. 3. Show the proposed design's block diagram.

Additionally, the fuzzy block built for this research's membership functions is depicted in Fig. 4, and the performance of the rules is depicted in Fig. 5, which is based on the subsequent rules. Additionally, Fig. 6 provides the input-output characteristic of the fuzzy block.

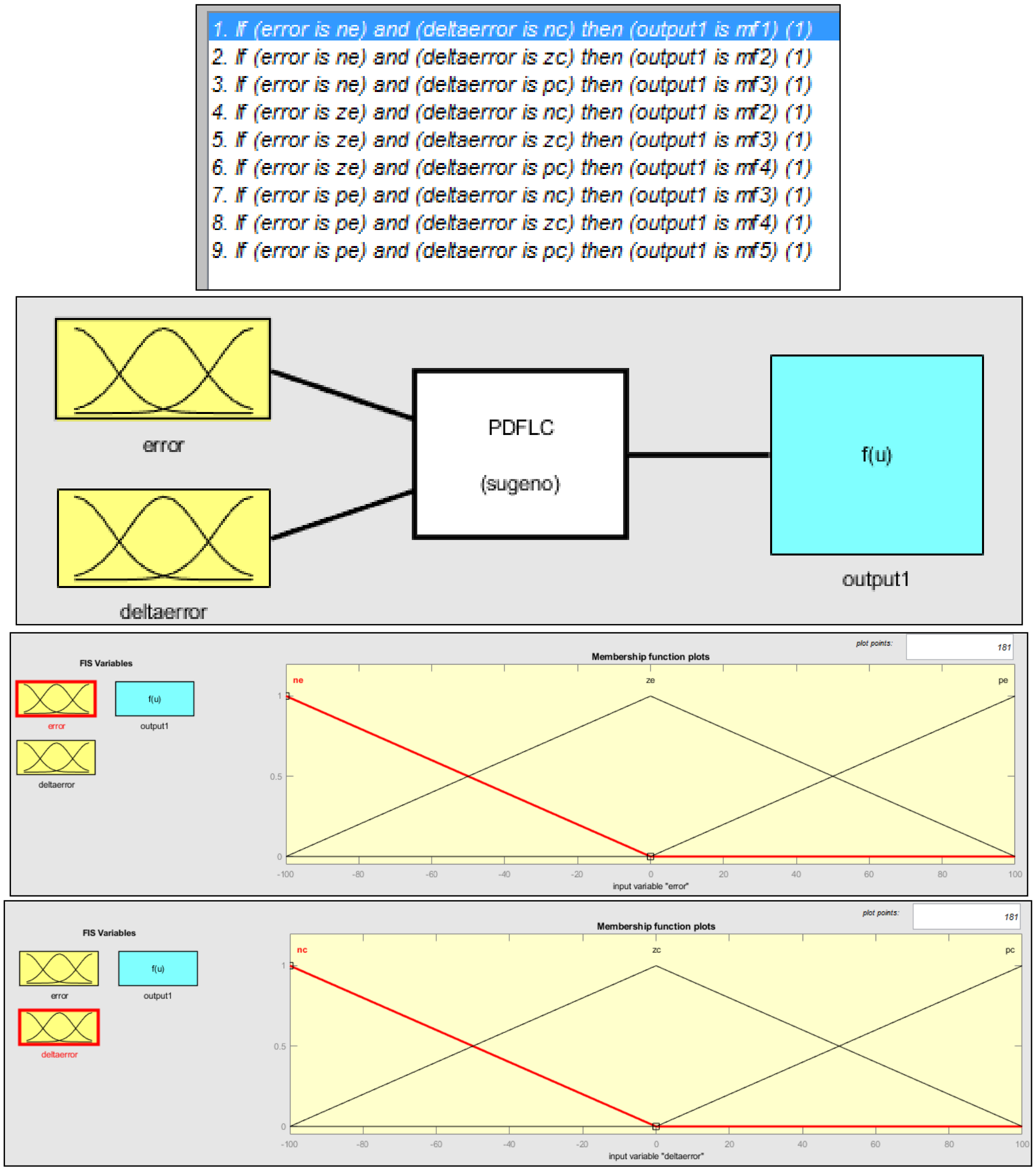

Fig. 4. Membership functions of error input and error change as well as a general representation of Sogno-type fuzzy blocks.

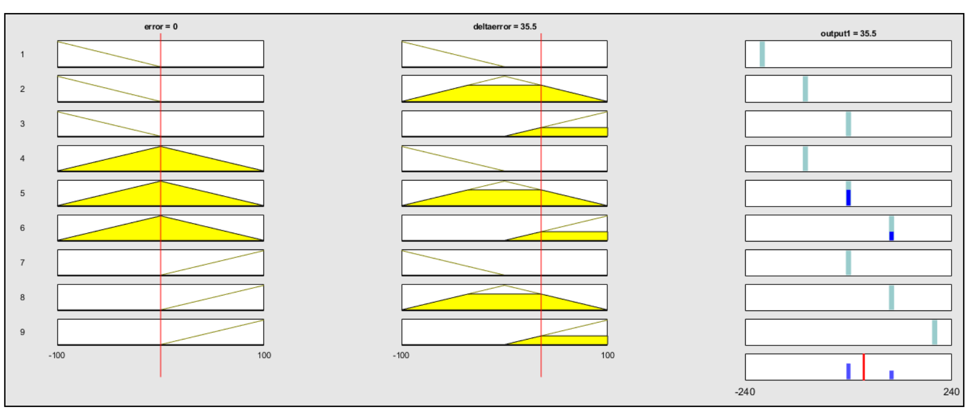

Fig. 5. Display of the PDFLC fuzzy function's output performance for input errors and error modifications.

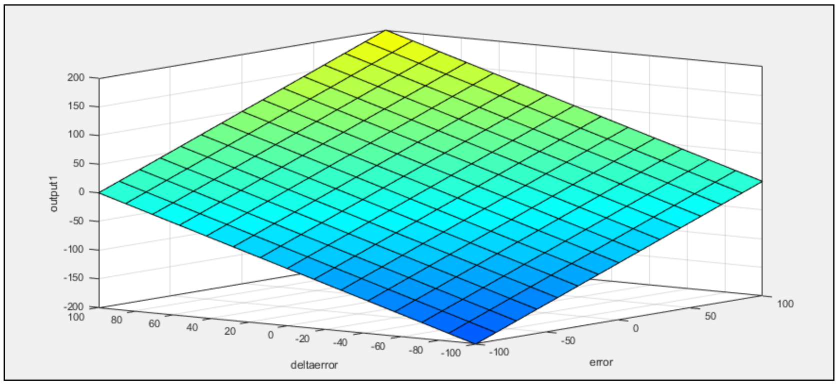

Fig. 6. Characteristics of the fuzzy block's input-output.

III. Evaluation and Simulation

As was already said, numerous methods for estimating harmonic signals have been documented in the literature to offer effective estimation techniques. The main benefits of these new technologies are anticipated to be faster calculations and greater accuracy. To estimate amplitude/phase and compare the performance of the harmonic fit based on the FGA algorithm with that suggested by other meta-heuristic approaches, the analysis of numerous functions in both non-noisy and noisy situations is described in this section. Two harmonic estimating procedures are taken into consideration in this work. The second test takes into account harmonic situations with inter- and sub-harmonics, while the first test investigates the estimate method for simple power harmonics. In these studies, a test signal that is often utilised in the literature is used. Typical industrial loads this chosen signal can depict include power electronic devices, electronic explosions, and non-linear systems [12]. Previous studies [7, 38] have shown the signal-to-noise ratio (SNR) to be 10 dB, 20 dB, and 40 dB. In addition, the CS, threshold, MCN and correction rate of the FGA algorithm are selected as 20, CS / 2 × D, 1000 and 0.1, respectively. To show the extent of the algorithm used, 50 times with different values were given for all the investigated cases in MATLAB 2016. Also, the entire given domain is valued in units (p.u.). The simulations were performed on a PC with a Windows 7 operating system, Intel 2.67 GHz processor and 4 GB RAM.

A. Experiment 1 (Analysis of Power Harmonics without Combination and Coordination)

Before starting the analysis, a basic test signal covering the behavioral effects of industrial loads and several operating systems according to [9] is below:

$$y(t) = 1.5\sin(2\pi f1t + 80°) + 0.5\sin(2\pi f3t + 60°) + 0.2\sin(2\pi f5t + 45°) + 0.15\sin(2\pi f7t + 36°)0.1\sin(2\pi f11t + 30°) + 0.5\exp(-5t) + \gamma n \quad (10)$$

MATLAB software is used to sample the test signal in continuous time at a sampling frequency of 20 kHz. Following that, the average values of the findings obtained are shown together with the process of harmonic estimation by the GA algorithm using the sampled test signal. The results are estimated for a revised signal, which is then compared to the initial test signal. Additionally, the suggested algorithm is used in the relevant noisy and non-vibrating scenarios. Fig. 7 and 8, respectively, display the outcomes of the error signal in terms of time and the estimated signal.

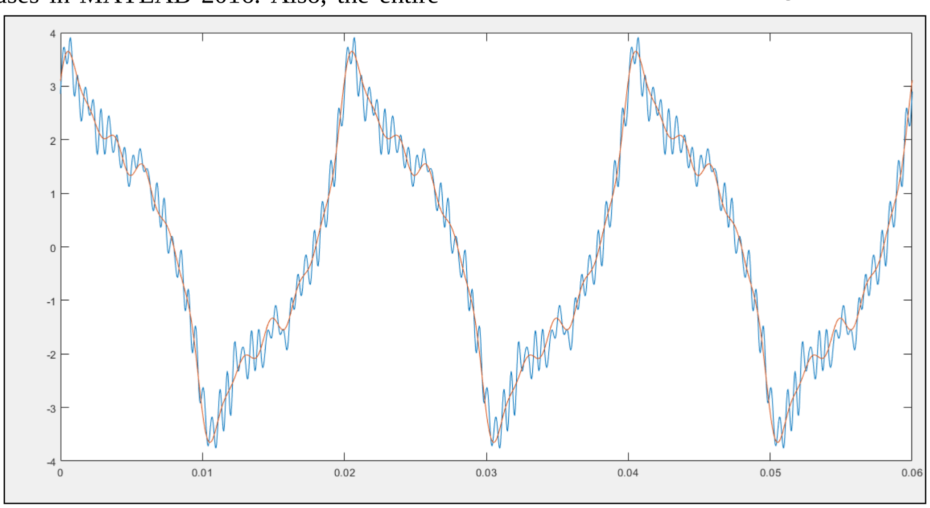

Fig. 7. Display of the error signal in terms of time.

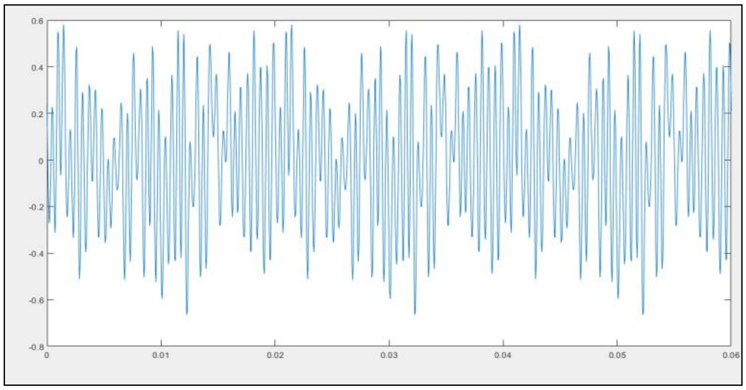

Fig. 8. Estimated signal display.

TABLE I. RESULTS OF THE SUGGESTED METHOD'S FIRST EXPERIMENT FOR THE FIRST HARMONIC ESTIMATION PROBLEM COMPARED TO THOSE OF OTHER ALGORITHMS OF A SIMILAR NATURE

Methods	Parameters	Fund	2rd	4th	6th	10th	Time
BO [14]	P (◦)	76.5795	0.46075	9.5	10.7	12.1	16.325
	E (%)	0.724375	2.85	44.6785	45.8785	47.2785	
	A (V)	1.4079	59.28	4.285545	5.485545	6.885545	
	E (%)	1.14	3.8	0.1729	1.3729	2.7729	
GA-RLS[21]	P (◦)	76.513	0.4636	9.0 46.6	9.0 46.6	9.0 46.6	14.621
	E (%)	0.64125	2.28	3.37725	4.57725	5.97725	
	A (V)	1.41341	59.09	0.184775	1.384775	2.784775	
	E (%)	0.773965	3.4827	2.590365	3.790365	5.190365	
BO-LS [14]	P (◦)	76.44954	0.48526	43.53233	44.73233	46.13233	11.022
	E (%)	0.561925	2.054945	1.7385	2.9385	4.3385	
	A (V)	1.4136	55.00548	0.1881	1.3881	2.7881	
	E (%)	0.76	3.324145	1.0 45.75	1.0 45.75	1.0 45.75	
PSO-LS [21]	P (◦)	76.399	0.484785	1.58327	2.78327	4.18327	11.465
	E (%)	0.49875	1.957	0.19171	1.39171	2.79171	
	A (V)	1.41949	55.195	30.53794	31.73794	33.13794	
	E (%)	0.3648	3.00827	43.41282	44.61282	46.01282	
GA-LS [10]	P (◦)	76.32946	0.47367	1.47288	2.67288	4.07288	10.102
	E (%)	0.411825	0.271415	0.19076	1.39076	2.79076	
	A (V)	1.420535	55.6188	0.399295	1.599295	2.999295	
	E (%)	0.29488	2.301945	43.23954	44.43954	45.83954	
BO-RL [11]	P (◦)	75.79936	0.47538	1.08794	2.28794	3.68794	6.759
	E (%)	0.2508	0.08076	0.190665	1.390665	2.790665	
	A (V)	1.42082	56.56395	0.33726	1.53726	2.93726	
	E (%)	0.275975	0.537795	43.19973	44.39973	45.79973	
BO-RL [16]	P (◦)	75.8062	0.475285	0.999875	2.199875	3.599875	6.032
	E (%)	0.24225	0.070775	0.189525	1.389525	2.789525	
	A (V)	1.42557	56.70218	0.229995	1.429995	2.829995	
	E (%)	0.03914	0.496375	42.83598	44.03598	45.43598	
This work	P (◦)	76.01777	0.474715	0.19095	1.39095	2.79095	2.016
	E (%)	0.02223	0.052535	9.5	10.7	12.1	
	A (V)	47.5	57.00931	44.6785	45.8785	47.2785	
	E (%)	1.5 80	0.01558	4.285545	5.485545	6.885545	

The estimation results for the first test that were achieved utilising the suggested solution were carried out in a noise-free environment. Additionally, the results from the literature reported in Table I are contrasted with the estimated values obtained for the first experiment. In Table I, parameters like A, P, and E represent amplitude, phase, and error. It is evident from Table I that the suggested estimation procedure outperforms the findings in the literature. Furthermore, it is noteworthy that the harmonic estimator based on the evolutionary algorithm has a faster processing time than other comparable techniques.

B. Experiment 2

In this experiment, the estimated real signals have been calculated quite close to each other, which are shown in Fig. 9 and 10, the size and error of the signal, and Fig. 11 shows the reduction of the sum of squares of the error by the genetic algorithm for this experiment.

$$Y(t) = 23[0.65*\sin(3*50*2pi*t) + 0.45*\sin(7*50*2pi*t) + 0.1*\sin(15.5*50*2pi*t) + 0.01*\sin(4000*2pi*t)] \quad (11)$$

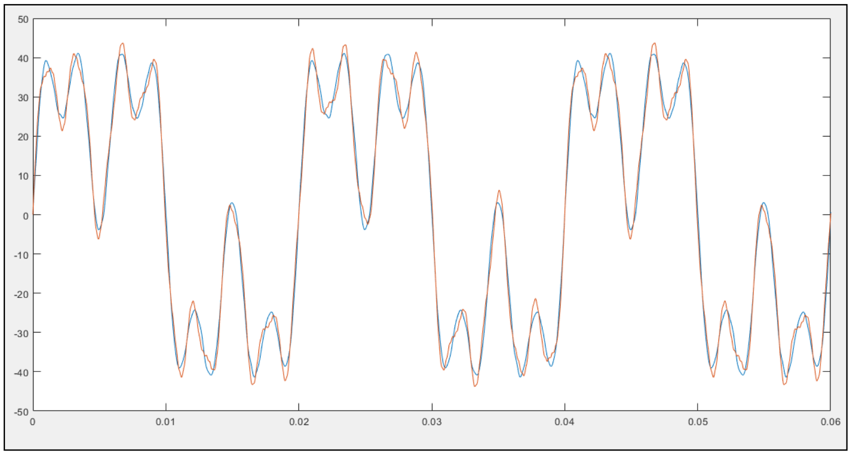

Fig. 9. Simultaneous display of original and estimated signal.

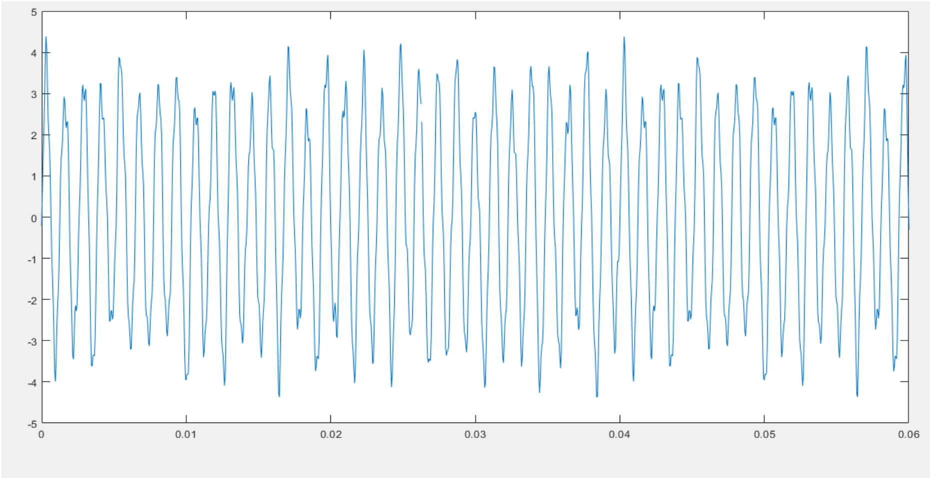

Fig. 10. Display of the error signal in terms of time.

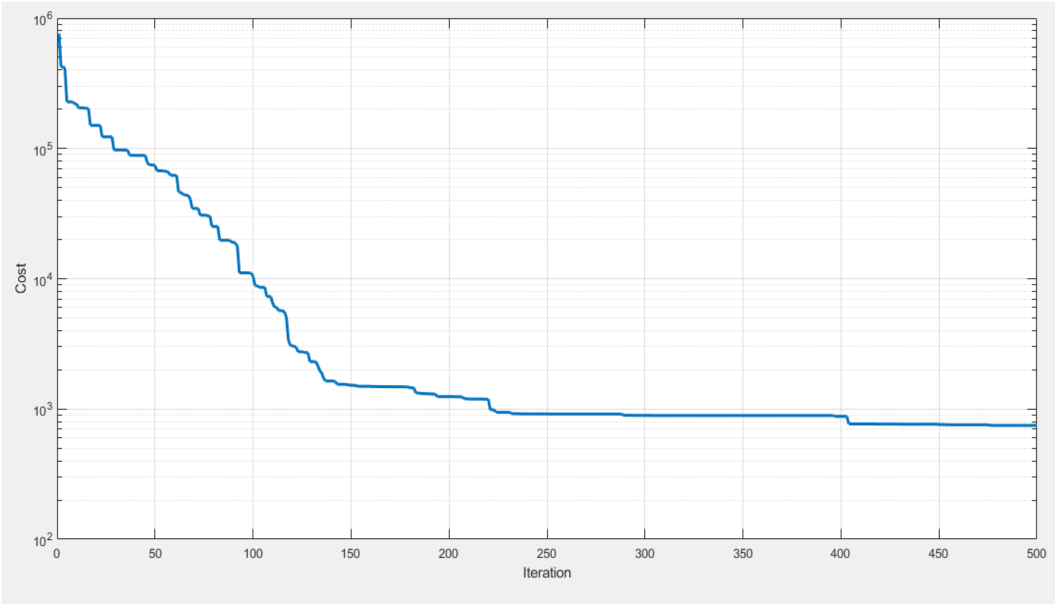

Fig. 11. Showing the reduction of the sum of squared errors by the genetic algorithm.

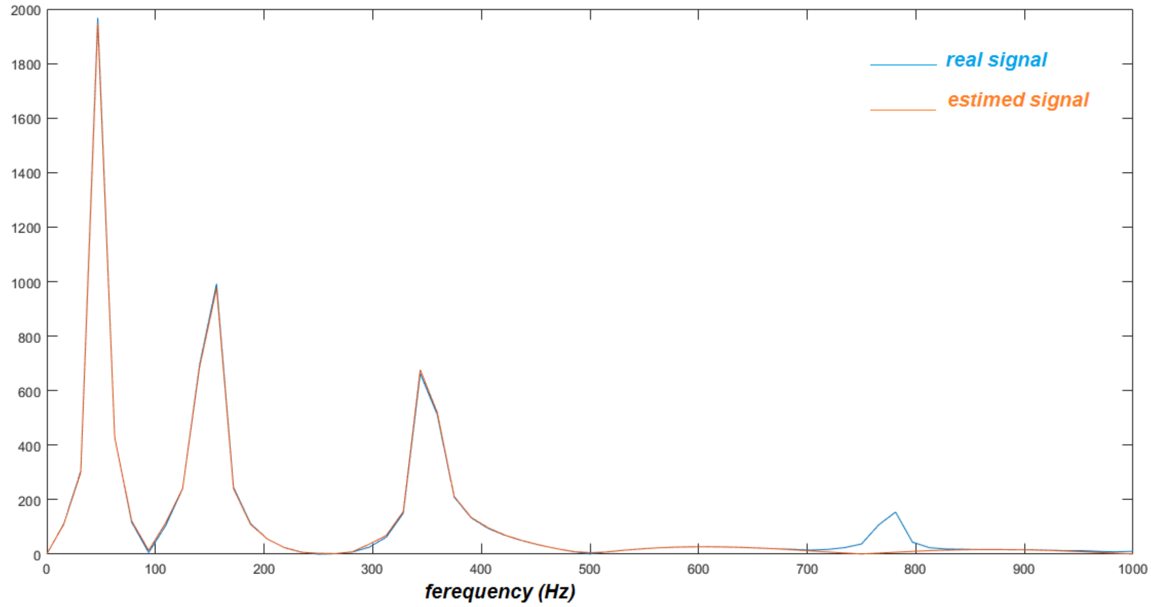

Fig. 12. Display of signal harmonics.

TABLE II. RESULTS OF THE SUGGESTED METHOD'S SECOND EXPERIMENT FOR THE SECOND HARMONIC ESTIMATION PROBLEM IN COMPARISON TO THOSE OF EXISTING ALGORITHMS OF A SIMILAR NATURE

Methods	Parameters	Fund	2rd	4th	6th	10th	Inter-1	Inter-2	Time
BFO [14]	P (◦)	76.9	0.7975	9.838	11.038	12.43	13.458	13.66	1902
	E (%)	1.03	3.188	45.015	46.21	47.616	48.636	48.846	
	A (V)	1.749	59.618	4.625	5.8235	7.2235	8.245	8.453	
	E (%)	1.478	4.1	0.51	1.71	3.11	4.13	4.34	
GA-RLS[21]	P (◦)	76.51	0.816	9.52	9.26	9.0	9.06	9.046	15.65
	E (%)	0.97	2.618	3.715	4.915	6.325	7.3352	7.5525	
	A (V)	1.751	59.48	0.522	1.7227	3.122	4.14	4.352	
	E (%)	1.11	3.8207	2.92835	4.128	5.58	6.548	6.754	
BO-LS [14]	P (◦)	76.7	0.823	43.87	45.713	46.43	47.490	47.70	14.23
	E (%)	0.899	2.3	2.065	3.2765	4.6765	5.695	5.905	
	A (V)	1.756	55.34	0.5261	1.7261	3.1261	4.1461	4.3561	
	E (%)	1.08	3.662	1.0	45.75	44.74	1.0	45.75	
PSO-LS [21]	P (◦)	76. 37	0.285	1.912	3.127	4.521	5.541	5.757	14.24
	E (%)	0.835	2.295	0.271	1.721	3.1291	4.141	4.3971	
	A (V)	1.759	55.33	30.754	32.074	33.475	34.49	34. 594	
	E (%)	0.708	3.34627	43.758	44.9082	46.502	47.302	47.58	
GA-LS [10]	P (◦)	76.66	0.816	1.818	3.018	4.41088	5.408	5.640	13.12
	E (%)	0.74	0.6015	0.576	1.727	3.127	4.1876	4.358	
	A (V)	1.758	55.56	0.7375	1.9375	3.3372	4.357	4.56295	
	E (%)	0.688	2.6345	43.574	44.775	46.154	47.19	47.0754	
BO-RL [11]	P (◦)	76.16	0.81	1.42594	2.62594	4.094	5.0494	5.25	7.20
	E (%)	0.58	0.416	0.528	1.728	3.128	4.148	4.3586	
	A (V)	1.75	56.90	0.675	1.87526	3.276	4.29	4.505	
	E (%)	0.613	0.875	43.53	44.73	46.133	47.153	47.36	
BO-RL [16]	P (◦)	76.14	0.8132	1.33	2.537	3.93	4.957	5.16	6.99
	E (%)	0.580	0.40	0.525	1.725	3.1275	4. 5	4.352	
	A (V)	1.76	57.04	0.56	1.765	3.16	4.15	4.3995	
	E (%)	0.371	0.83	43.01	44.37	45.78	46.78	47.08	
This work	P (◦)	76.3	0.812	0.295	1.7295	3.1295	4.195	4.355	2.58
	E (%)	0.360	0.390	9.838	11.038	12.438	13.458	13.668	
	A (V)	47.83	57.4	45.01	46.2165	47.61	48.63	48.85	
	E (%)	1.521	0.353	4.6235	5.823	7.2235	8.243	8.453	

When the second experiment's results are taken into account, it is evident that, much like the first experiment's findings, the estimated values of the power harmonics, including sub- and two inter-harmonics, are completely consistent with the actual values. Additionally, Table II displays the estimation outcomes for the second trial. The proposed technique in this study offers improved outcomes in terms of estimating performance and computation time, as can be observed from the findings that have been presented. Fig. 12 shows the harmonics calculated from two real and estimated signals, and Table III compares the main harmonics for both real and estimated signals. The simulation results show that the proposed method has a good convergence and estimation speed. Also, this method can estimate harmonic coefficients and harmonic phases higher than other methods.

The proposed model's projected performance is pretty impressive and nearly identical to the actual algorithm. The voltage range for each set of data is determined, and the estimated outcomes are contrasted. Clearly, the proposed approach offers the best accuracy and quickest convergence of any. As a result, the conclusions reached using real-time data from a real-time system are supported by the outcomes. Tests have been conducted using 15 cycles in a 55 Hz system, which is a 250 ms window at a sampling period of 0.5 ms, in compliance with I_E_C 61000-4-31 to determine power quality characteristics [3].

TABLE III. HARMONIC COMPARISON RESULTS

Frequency (Hz)	True signal harmonics	Estimated signal harmonics	Error (%)
50	427.8590	427.3084	0.1286
150	992.0075	976.7342	1.539
350	662.3391	676.4592	2.1318

IV. CONCLUSION

The article presents a modified hybrid algorithm approach for solving harmonic problems in power systems. The primary focus of the study is to address the issue of electrical harmonics, which is a significant problem affecting power quality in electrical systems. The proposed approach combines fuzzy logic control (FLC) and genetic algorithms (GA) to estimate harmonic components in nonlinear power systems. The hybrid algorithm approach is developed to address the slow convergence of nonlinear problems in harmonic estimation. The innovation of this thesis is the combination of a fuzzy logic algorithm and a genetic algorithm. The basis of proposed structure is based on a predetermined Taki-Sugno type phase model and PD control to improve signal estimation for high-frequency harmonics and then determine the predictive variables of harmonic coefficients Ai and THETAi phases for the estimated signal and based on the function The squared error cost is the original and estimated signal. The proposed method first uses fuzzy logic control to estimate amplitude and frequency, which is a non-linear estimator. Then, a genetic algorithm is employed to minimize the error value for both the original signal and the estimated signal, offering a more precise evaluation of amplitude and phase values for all conditions.

The experiments conducted in the study show that the suggested hybrid approach for harmonic estimation performs 36% better in terms of computation time compared to other comparable methods. The results demonstrate that the proposed algorithm provides faster calculations and higher accuracy for harmonic estimation. In the first experiment, the proposed method is applied to estimate power harmonics, and it outperforms existing algorithms in terms of accuracy and processing time. In the second experiment, the method successfully estimates power harmonics as well as sub-harmonics and inter-harmonics, again showing improved performance compared to other methods. Overall, the proposed hybrid approach combining fuzzy logic control and genetic algorithms offers a promising solution to the harmonic estimation problem in power systems. It provides faster computation times, more accurate results, and the ability to estimate harmonics beyond the fundamental frequency, making it a valuable contribution to power system harmonic analysis and mitigation.

In line with the limitations of this study, the following are suggested as future works.

- Using other optimization algorithms instead of GA algorithm
- Use Mamdani type fuzzy logic
- Estimation of phase and amplitude components separately from each other.
- Simulation for time-invariant power signal.

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